# Study of Calibration Techniques

A Demonstration of a Transducers Response to High Pressure Dynamic Loads

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21st Transducer Workshop June 22, 2004



## Two Decades of History

- Calibration differences between government and / or contractor installations have been under scrutiny for years.
  - In a 1983 report (Ref. #1) the author concluded there was a significant difference between calibration results with the probable cause being calibration methods.
  - In a 1993 report (Ref. #2) the author concluded that there was still a significant difference in the calibration results obtained from 5 different facilities and listed the probable causes.

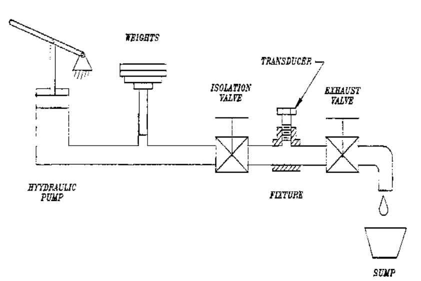
| *Probable Cause* | *Estimated Effect* |
|---|---|
| Pressure Generation | +/-0.2% |
| Calibration Electronics | +/-0.2% |
| Calibration Method | +/-0.7% |
| Transducer | +/-0.4% |
| Bad Transducer | +/-1.25% |

## Two Decades of History (cont.)

- In 2002 a calibration discrepancy was identified between Tourmaline, Quartz Transducers and Copper Crushers.
- So based on the 2002 discrepancies and the information from the 1983 and 1992 reports this 2003 investigation set out to further understand the possible causes of calibration error that still exist two decades later.
- Testing was conducted at:
  - YTC's Transducer Manufacturing and Calibration facility
  - ATC's ISO 17025 accredited Transducer Calibration Laboratory (TCL)

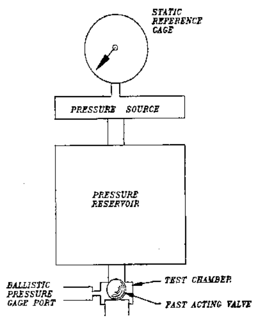


## Static Pressure Primary Standard




ATC's Pseudo-Dynamic Negative Calibration Method or "Pressure Release Method".

# Static Pressure Secondary Standard




YTC's Pseudo-Dynamic Positive Calibration Method or "Positive Pressure Step Method"



# Pressure Generation Results

| ***Primary / Secondary Calibration Comparison for ATC and YPG*** | | | | | |
|---|---|---|---|---|---|
| ***YTC*** | | | ***ATC*** | | ***Difference*** |
| *DH Primary Std.* | *Strain Cell* | *Mangannon Cell* | *DH Primary Std.* | *Mangannon Cell* | *ATC / YTC* |
| 20,000 | 19,840 | 19,990 | 20,000 | 20,000 | -0.09% |
| 40,000 | 39,800 | 40,000 | 40,000 | 39,980 | +0.04% |
| 60,000 | 59,740 | 60,020 | 60,000 | 59,980 | +0.07% |
| 80,000 | 79,680 | 80,030 | 80,000 | 80,028 | +0.10% |
| 100,000 | 99,580 | 100,040 | 100,000 | 100,024 | +0.14% |

## Calibration Electronics

- Minimum Transducer Calibration Electronics
  - Signal Conditioning (Charge Amplifier)
  - Calibration Capacitor (Weakest Link)
  - Readout Instrumentation (Simple – Sophisticated)
    - YTC uses the Kistler 504 Series Charge Amplifier, National Instruments A/D
    - ATC uses the Kistler 5011Series Charge Amplifier, Data Com A/D

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## Calibration Capacitor Results

| *Pre-Instrumentation Check (Using Indicated Cap Values)* | | | |
|---|---|---|---|
| *Channel No.* | *Calculated* | *Measured* | *Diff.* |
| 1 | 25126.12pC | 25061 pC | -0.26% |
| 3 | 25125.12 pC | 25078 pC | -0.19% |

Induced Error

| *Calibration Capacitor Check* | | | |
|---|---|---|---|
| *Serial No. / Channel No.* | *Recorded Value* | *Measured Value* | *Diff.* |
| 3502 / 1 | 9,987pF | 10,014pF | -0.26% |
| 1025C / 3 | 9,976pF | 9,988pF | -0.12% |

Cap. Error

Calibration Correction

| *Post-Instrumentation Check (Using Corrected Cap Values)* | | | |
|---|---|---|---|
| *Channel No.* | *Calculated* | *Measured* | *Diff.* |
| 1 | 25119.11pC | 25140.0pC | 0.08% |
| 3 | 25118.11pC | 25123.0pC | 0.02% |

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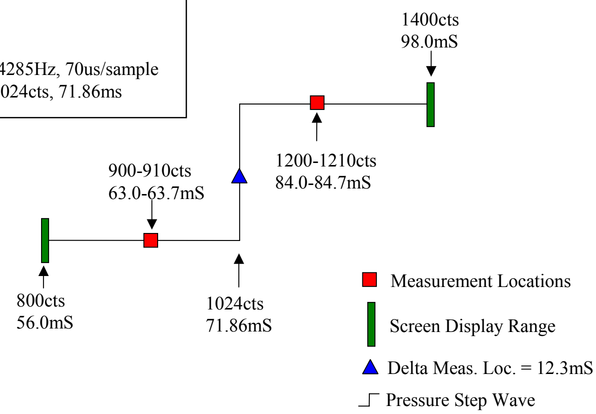
# YPG Calibration Methods

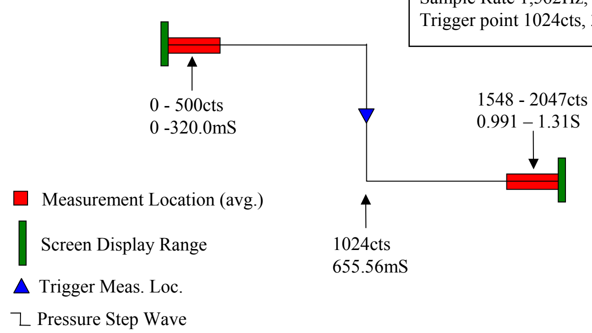
***YPG DAQ Specifications:***
12 Bit A/D
Pre-trigger 1k
Post-trigger 1k
Sample Rate 14285Hz, 70us/sample
Trigger point 1024cts, 71.86ms






# ATC Calibration Method

***ATC DAQ Specifications:***
12 Bit A/D
Pre-trigger 1k
Post-trigger 1k
Sample Rate 1,562Hz, 640us/sample
Trigger point 1024cts, 327.68ms

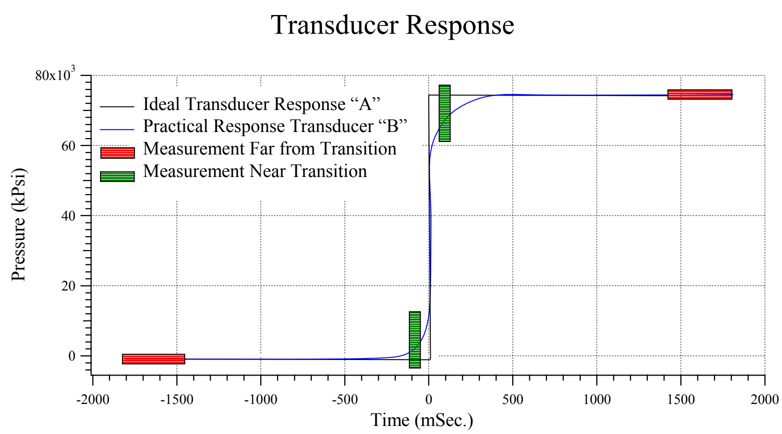


## Calibration Method Results

- A +/-0.7% error was attributed to the use of different calibration methods based on the 1992 report.
- The data in this report shows that the calibration method has little or no effect on the results when the transducer produces an ideal flat response.
- No transducer produces a perfect flat response, so the calibration method, the data acquisition approach and the data reduction are critical.



## Ideal vs. Practical Transducer Response

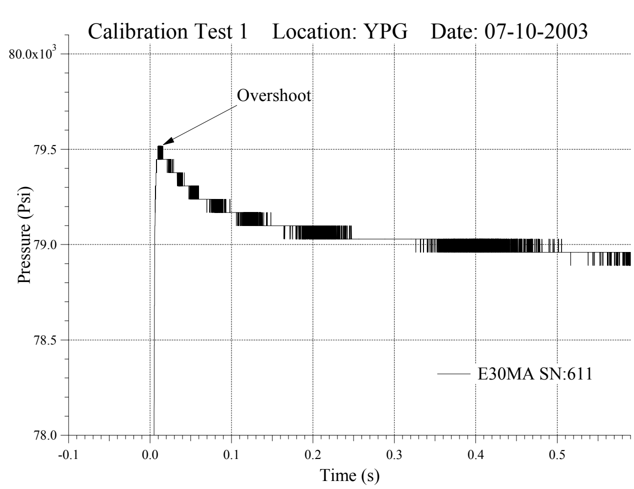


## Transducer Types

- Tourmaline Crystals
  - YTC / Kistler E30MA (0-120kPsi)
  - YTC RP120 (0-30kPsi)
    - Cusp / Overshoot Anomaly
    - Time Constant / Drift Issues
- Quartz Crystals
  - Kistler 6213B (0-120kPsi)
  - Kistler 6205AM01 (0-100kPsi)
    - Torque / Mount Issues



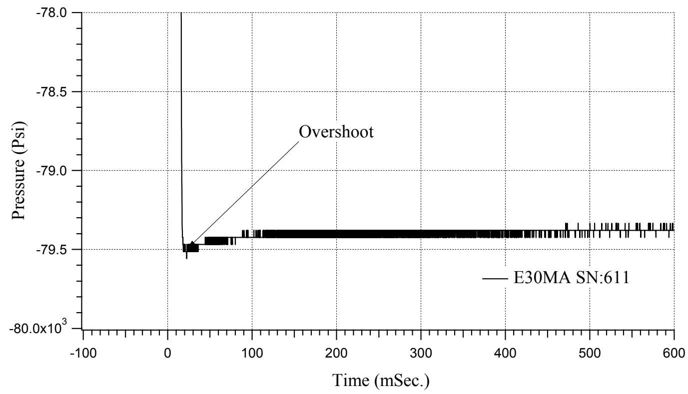
## Tourmaline Crystals
## E30MA Overshoot or "Cusp" Phenomenon




Positive Pressure Step Method

# Tourmaline Crystals
# E30MA Overshoot or “Cusp” Phenomenon

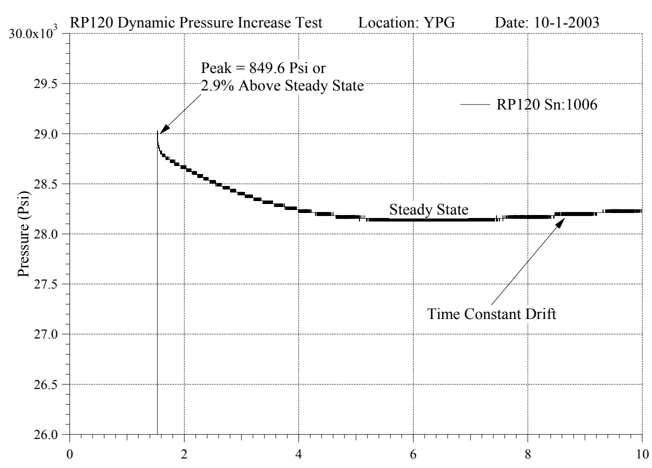
Calibration Test Location: ATC Date: 04-25-2003




Pressure Release Method

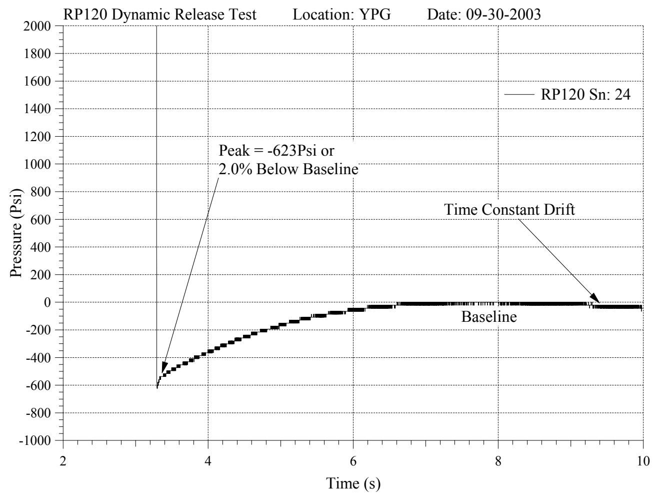


# Tourmaline Crystals
# RP120 Overshoot or “Cusp” Phenomenon




Positive Pressure Step Method

## Tourmaline Crystals
## RP120 Overshoot or "Cusp" Phenomenon




Pressure Release Method



## Tourmaline Crystals

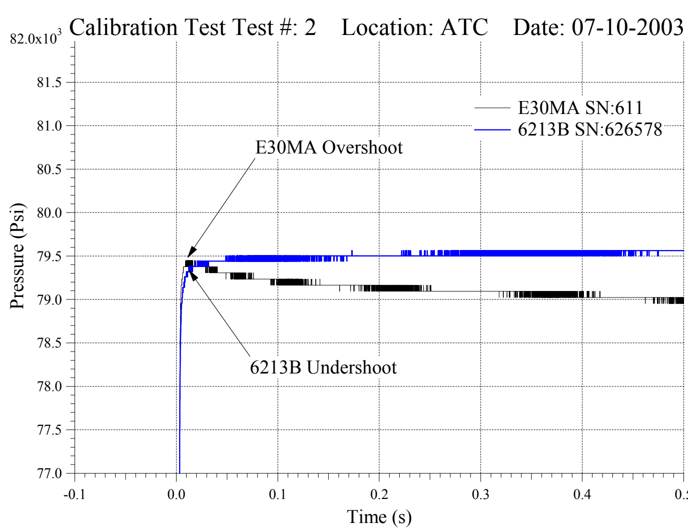
- Must be Calibrated Dynamically
  - To Account for:
    - Overshoot / Cusp
    - Short Time Constant
    - Drift
  - The calibration method is critical
    - The calibration method should mimic the measurement to be made.
  - Calibration measurement locations are critical

## Quartz Crystals
## Mount & Torque Sensitivity

- Problem Resolution:
  - Mounting Surface Preparation
    - Proper Thread Depth
    - Insure Sealing Surface is:
      - Perfectly Flat
      - Perfectly Clean
  - Firing Adapters / Calibrate Assembly
  - Triple Torque
    - Torque Transducer / Remove Torque (3 Times)
  - Thermal Protective Shield
    - Causes Transducer to Indicate a Lower Pressure



## Kistler 6213B vs. E30MA Wave Shape

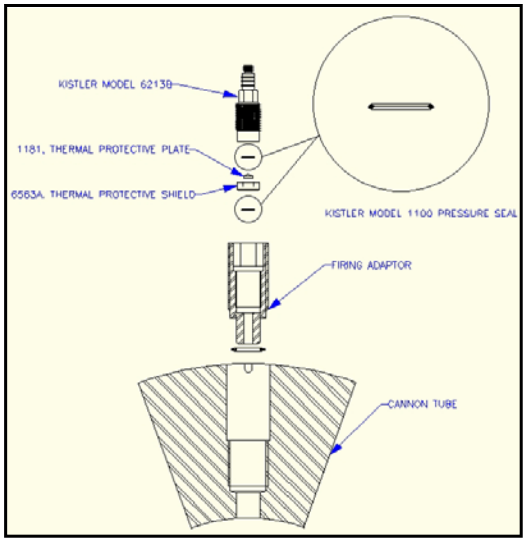


## Quartz Crystals
## Mount & Torque Sensitivity

Firing

Adapter

Assembly






## Kistler 6213B
## Thermal Protection Sensitivity

| ***Kistler 6213B SN:626578*** | | | | |
|---|---|---|---|---|
| ***Thermal Protection*** | ***Dynamic Pressure Step*** | ***"True Pressure" (PSI)*** | ***Measured Pressure (PSI)*** | ***Percent Difference (%)*** |
| No | Positive | 79,104 | 79,122 | +0.02 |
| No | Positive | 79,100 | 79,447 | +0.18 |
| No | Negative | 80,000 | 80,023 | +0.02 |
| Yes | Positive | 79,305 | 78,942 | -0.40 |
| Yes | Positive | 80,008 | 79,652 | -0.44 |
| Yes | Negative | 79,780 | 79,342 | -0.54 |

# Other Issues

- Transducer Durability
  - Since 1990 ATC has had 225 E30MA's
    - To Date 30 Remain in Inventory
    - On average 15 E30MA transducers are removed from inventory each year.
  - Since 1990 ATC has had 13 Kistler 6213B's
    - To Date 12 Remain in Inventory.



# Other Issues (cont.)

| ***Sensitivity Level Shift Test*** *(10 repetitions at each configuration)* | | | | | | |
|---|---|---|---|---|---|---|
| ***Configuration*** | ***Gage to Gage Var.*** | ***Within Gage Var.*** | ***Round to Round Var.*** | ***Worst Deviation*** | ***Extreme Spread*** | ***Round No.*** |
| 4-E30MA's (From Shelf) | 0.63% | 0.06% | 0.12% | 1.68% | 1.93% | PH01-10 |
| Re-Calibrate (In Place) | 0.05% | 0.04% | 0.12% | 0.58% | 0.48% | PH11-20 |
| 4-E30MA's (From Shelf) | 0.65% | 0.07% | 0.06% | 1.07% | 1.81% | PH41-60 |
| 4-6213B's (From Shelf) | 0.28% | 0.05% | 0.05% | 1.10% | 0.86% | P001-10 |
| Re-Calibrate (In Place) | 0.05% | 0.04% | 0.03% | 0.17% | 0.23% | P011-20 |
| 4-6213B's (From Shelf) | 1.00% | 0.06% | 0.06% | 1.35% | 2.28% | P051-60 |

## Other Issues (cont.)

| Torque / Mount Sensitivity Test (10 repetitions at each configuration) | | | | | | |
|---|---|---|---|---|---|---|
| ***Configuration*** | ***Gage to Gage Var.*** | ***Within Gage Var.*** | ***Round to Round Var.*** | ***Worst Deviation*** | ***Extreme Spread*** | ***Round No.*** |
| 4-E30MA's (From Shelf) | 0.63% | 0.06% | 0.12% | 1.68% | 1.93% | PH01-10 |
| Re-Calibrate (In Place) | 0.05% | 0.04% | 0.12% | 0.58% | 0.48% | PH11-20 |
| Changed Ports (Retorqued) | 0.07% | 0.06% | 0.11% | 0.35% | 0.64% | PH31-40 |
| 4-E30MA's (From Shelf) | 0.65% | 0.07% | 0.06% | 1.07% | 1.81% | PH41-60 |
| 4-6213B's (From Shelf) | 0.28% | 0.05% | 0.05% | 1.10% | 0.86% | P001-10 |
| Re-Calibrate (In Place) | 0.05% | 0.04% | 0.03% | 0.17% | 0.23% | P011-20 |
| Changed Ports (Retorqued) | 0.80% | 0.05% | 0.06% | 1.64% | 2.06% | P041-50 |
| 4-6213B's (From Shelf) | 1.00% | 0.06% | 0.06% | 1.35% | 2.28% | P051-60 |



## Calibration Discrepancies

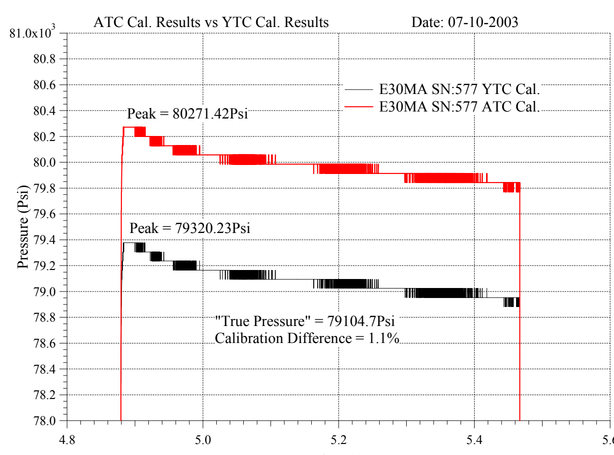
- In 1989 ATC forced the Copper Crusher Tarage Tables to agree with the Tourmaline transducers.
- In 1990 ATC's analysis of the Bourges Copper Crusher data (based on quartz transducers) indicated that the quartz sensors used by the French were reading 1.0% lower than the tourmaline sensors used by the USA.
- In 2002 the 1989 Copper Crusher Tarage table was again evaluated in the USA. The data indicated that the Copper Crushers no longer agree with the tourmaline transducers but now agree with the quartz transducers (approximately 0.8% lower than tourmaline).

# Calibration Test Setup

- Testing was limited to ATC & YTC
- The same transducers were used at each facility.
  - 2 each YTC E30MA's
  - 2 each Kistler 6213B's
- The same electronics equipment (signal conditioning, data acquisition) was used at each facility.
- Each facility used it's own calibrator and calibration method.

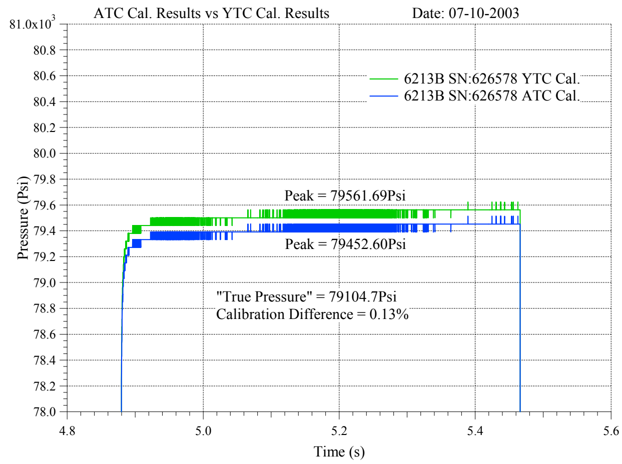


# Calibration Results




Same Tourmaline Transducer Calibrated at both ATC & YTC

## Calibration Results (cont.)




Same Quartz Transducer Calibrated at both ATC & YTC

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## Results Summary

- Quantification of bias and errors uncovered:

| | |
|---|---|
| 0.30% | ATC Calibration Error |
| +0.40% | E30MA Overshoot Error |
| 0.70% | Total Error Identified During Copper Crusher Tests |
| - 0.26% | YTC Instrumentation Error |
| *0.44% | Total Remaining Error |

* Gage-to-gage variability of the E30MA is on the order of approximately 0.6%.

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# Conclusion

1. Understand the one-size-fits-all for calibration does not always work.
2. Know how your transducer responds to your test environment.
3. Know how your transducer responds to your calibration method.
4. Understand the weak links in the calibration process.
   a. Calibration Capacitors (charge mode transducers).
   b. Measurement Locations (A/D digitizers)
   c. Secondary Sources (check often)
5. When using new transducers for the first time test them thoroughly.
6. Don't solely rely on statistics for your assurance.



# Acknowledgments / References



| ATC | YTC |
|---|---|
| Bill Burget | Welton Phillips |
| David Porter | David Smith |
| Scott Walton | |



No. 1 - Weddle, Arlen L., Methodology Investigation Final Report Pressure Transducer Calibration Comparison; Report No. APG-MT-5884, U. S. Army Aberdeen Proving Ground, MD, September, 1983

No. 2 - McMullen, Kenneth R., Final Report of Calibration Data on Transducers, Report No. CSTA-7388, U. S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD, December, 1992